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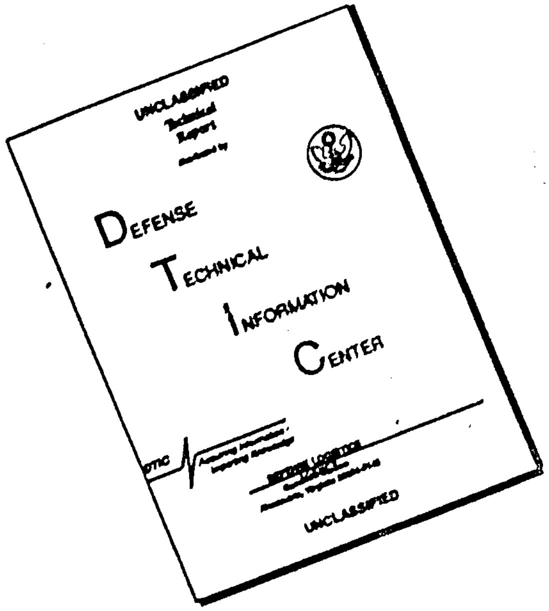

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AERODYNAMICS LABORATORY

WASHINGTON 7, D.C.

AIRCRAFT STORE TRAJECTORIES PREDICTED FROM WIND-TUNNEL INVESTIGATIONS COMPARED WITH FULL-SCALE FLIGHT RESULTS

by

Millard J. Bamber

Problem Assignment 3-32-04

July 1961

$1.60

B-11

SYMBOLS

t	time in seconds, full-scale flight time measured from start of launch
δ_a	aileron deflection
δ_e	elevator deflection
δ_r	rudder deflection
θ	angle of pitch (angle between the missile longitudinal axis and its projection on the horizontal plane)
ϕ	angle of roll (angle through which the missile has rolled about its longitudinal axis)
ψ	angle of yaw (angle through which the projection of the missile longitudinal axis on the horizontal plane has rotated about the vertical)
$\cdot$ (dot)	first derivative with respect to time (written over the symbol)

Notes: All angles in degrees. Rates of roll in degrees per second. Positive control angles give negative moments about the missile axes.

AERODYNAMICS LABORATORY
DAVID TAYLOR MODEL BASIN
UNITED STATES NAVY
WASHINGTON, D. C.

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SUMMARY

Some full-scale aircraft missile trajectory characteristics following launch from an airplane are compared with those predicted from wind-tunnel investigations. The predicted characteristics for the three available trajectories are believed to be in as good agreement as could be expected and for some factors, much better.

INTRODUCTION

The usefulness of trajectory predictions from wind tunnel test data depends upon how well the prediction agrees with comparable full-scale flight results. The Aerodynamics Laboratory of the Taylor Model Basin reported in Reference 1 the results of an investigation to predict the trajectory characteristics of a missile during and following its launch from a carrying airplane. Since publication of the report, data from three comparable full-scale flights have been made available by the Naval Missile Center, Point Mugu, California. This report gives some important characteristics of full-scale trajectories compared with those predicted from wind-tunnel results.

This investigation was conducted in accordance with Reference 2.

PROCEDURES FOR DETERMINING TRAJECTORIES

The trajectory characteristics for the missile were predicted by the use of wind-tunnel test data and equations of motion similar to those given in Reference 3. The airplane was assumed to fly a steady straight and level path. These characteristics were found by predicting the attitude and relative position of the airplane and missile at successive points. At each point, aerodynamic data were obtained and used to predict the following point. This process was started at the instant of missile release and was continued as long as desired.

For the flight, from zero time to one second (loss of altitude about 30 feet), wind-tunnel test data (about 10 test points for each trajectory) were obtained at selected intervals so that the mutual interference of the missile and airplane would be included in the aerodynamic coefficients. For the time after one second, because of limitations of wind tunnel size, the missile was assumed to be flying in free air (i.e., no mutual interference).

The full-scale free-flight trajectory characteristics were obtained from oscillograph records of attitude angles, rate of change of these angles with time, and control-surface deflections. Also, a plot of altitude of the missile versus time was furnished.

MISSILE, AIRPLANE, MODELS, AND APPARATUS

The missile has a low delta wing and a cruciform tail positioned at an angle of roll of 45° with respect to the wing. Each tail surface is rotated independently about its own spanwise axis so that combinations of the four deflected surfaces gave control about the three missile axes. The missile was ejected downward and forward from beneath the left wing of the A3D-2 airplane.

The wind-tunnel tests were conducted in the 7- by 10-Foot Transonic Wind Tunnel at Taylor Model Basin, using scale models of the missile and airplane. An electronic digital computer was used for performing computations necessary for prediction of the flight trajectory. The control surfaces on the missile model were fixed. For the computations, the aerodynamic moments for simulated control-surface deflections were estimated from isolated tests of the missile. The simulated deflections were computed according to equations furnished for the missile.

For the prediction of flight trajectories, the following series of events was simulated;

a. The controls were activated at 0.04 second after launch, to counteract angle of roll and rates of rotation about all axes.

b. At 2.00 seconds after start of launch, an additional pitch control was started, to increase the angle of attack to 16° at the rate of 2° per second and to "home" the missile on a target located at infinity.

c. After 3.30 seconds, simulated missile thrust was applied.

The same sequence of events was assumed to have been followed by the full-scale missile. Full-scale flight data were recorded as oscillograph records of "gyro" response and control-surface angles of the missile. Further details of the method of obtaining full-scale data are not available, nor are they considered to be of much importance here.

COMPARABILITY

For full-scale and predicted trajectory characteristics to be exactly comparable, all of a large number of conditions and sequences must be the same. In the first place, recorded data from both wind tunnel and flight should be accurate. Conditions at time of launch, such as effective altitude, Mach number, and velocities of translation and rotation, performance of launcher and response of the missile to control-surface deflection should be the same. For the predictions, however, the stability derivatives and the response to control-surface deflections were estimated from wind-tunnel test data. Moreover, exact theoretical similitude could not be obtained because shortly after launching the missile and airplane will have different velocities and flight-path angles. Both, however, must be tested in the wind tunnel at the same velocity. Because the airplane and missile have different flight path angles, their attitudes relative to each other and the angular settings with respect to the relative wind vector cannot both be correct.

RESULTS

Some of the characteristics of the three trajectories which were considered to be close enough in altitude and Mach number to be comparable are as follows:

Figure	Mach Number		Altitude in feet	
	Free-Flight	Predicted	Free-Flight	Predicted
1	0.86	0.90	22,500	20,000
2	0.83	0.80	30,000	30,000
3	0.80	0.80	39,000	40,000

For free flight, because of errors in evaluation of the oscillograph records, a displacement in the zero reference for the curves may be ±1° for control-surface deflections, ±2° for attitude displacements, and ±1/2° per second for the rates of rotation. The errors in individual values (in addition to the displacement of the zero reference) may be of the order of ±1/2° for control-surface angles, ±1° for attitudes, and ±2° per second for rates of rotation.

No adjustments have been made to any of the results to correct for differences in Mach number and altitude between free-flight and wind-tunnel data.

DISCUSSION

The predicted characteristics of the trajectories represent the full-scale characteristics as well as could be expected and in some respects, much better.

For the time up to 2 seconds, there should be a rough relationship between the loss of altitude and the angle of pitch, θ; i.e., the more negative the value of θ, the greater the loss of altitude should tend to be. This relationship between θ and loss of altitude is consistent between predicted and flight results for the conditions of Figures 1 and 3. For the conditions of Figure 2, it might be expected that the difference in loss of altitude would be more than is indicated by the small differences in θ. For the first 2 seconds, the automatic control is set to make and keep $\dot{\theta}$ equal to zero. In every case, $\dot{\theta}$ is practically zero after 0.5 second.

This difference in loss of altitude suggests the possibility that the missile was actually launched with an initial θ more negative than was used for the prediction, as indicated by Figure 3. The inconsistency between θ and the expected loss of altitude in Figure 2 could have been due to errors in θ and loss of altitude obtained from flight tests. The missile in flight, after a slight delay, attained the programmed rate of increase in the angle of attack as evidenced by the rate of increase of θ. It may be that there was a delay in missile control response in flight or that the target and missile were not at the same altitude. (For the predictions, the altitudes were assumed the same.)

The same general pattern of roll characteristics and magnitude of values was obtained in flight as had been anticipated from the prediction. It is gratifying to note that the large accelerations in roll and subsequent rate of roll, $\dot{\phi}$, and angle ϕ, which are undoubtedly due to the airflow interference of the airplane, were so well predicted. However, the mutual interference effects and their differences between flight and prediction tend to be masked by the control responses except at the start of the trajectory.

Most of the angles associated with yaw up to 2 seconds after launch are within the probable accuracy of measurement. For the time after 2 seconds, the motions are probably primarily dependent on conditions at 2 seconds, control deflections, target angle, and gusts.

No provision for cross control signals and aerodynamic control interactions were made for the prediction. However, the flight records indicate that these effects exist.

No effect of missile thrust (applied at 3.30 seconds) is evident from either the predicted or free-flight results.

CONCLUSION

For this particular airplane-missile configuration and the three predicted and flight trajectories that had comparable altitudes and Mach numbers, the wind-tunnel test methods gave a good prediction of the full-scale trajectory characteristics.

Aerodynamics Laboratory
David Taylor Model Basin
Washington, D. C.
July 1961

REFERENCES

1. Bamber, Millard J. Two Methods of Obtaining Aircraft Store Trajectories From Wind Tunnel Investigations. Wash., Jan 1960. 22 l. incl. illus. (David Taylor Model Basin. Aero Rpt 970).
2. BUAER CONF ltr Aer-AD-311 Ser 01606 of 3 Feb 1958.
3. Bamber, Millard J. and H. Dulany Davidson, Jr. Equations for Computing Trajectories of a Store Launched From an Airplane. Wash., Sept 1960. 32 l. incl illus. (David Taylor Model Basin. Aero Rpt 981)

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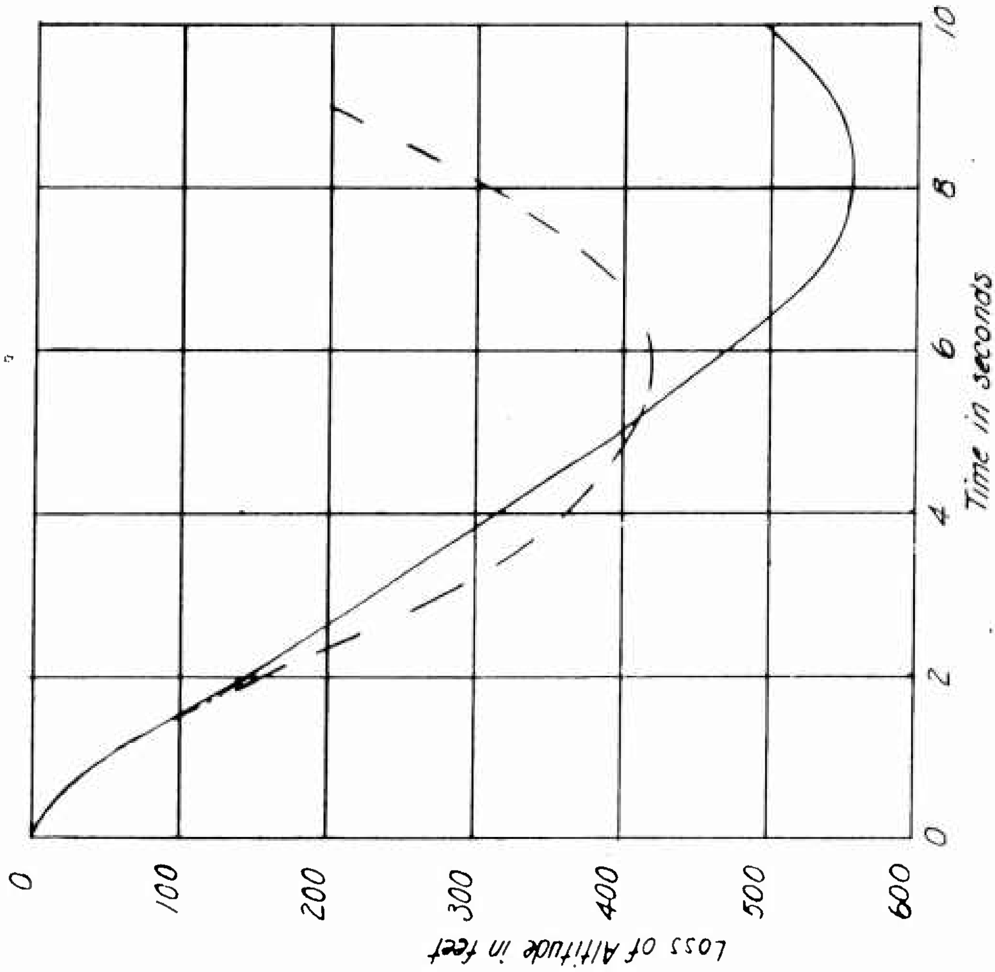
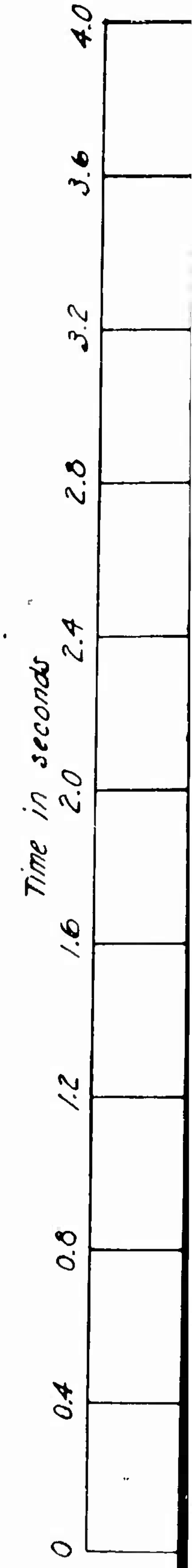
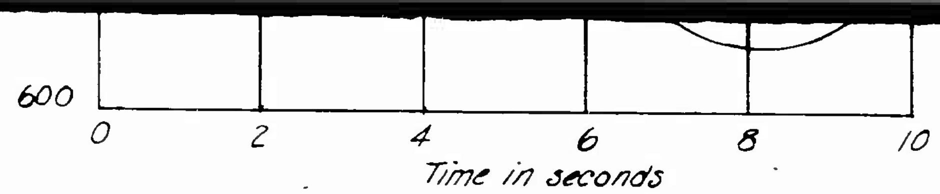


Time in seconds
0
2
4
6
8
10
Loss of Altitude in feet
0
100
200
300
400
500
600

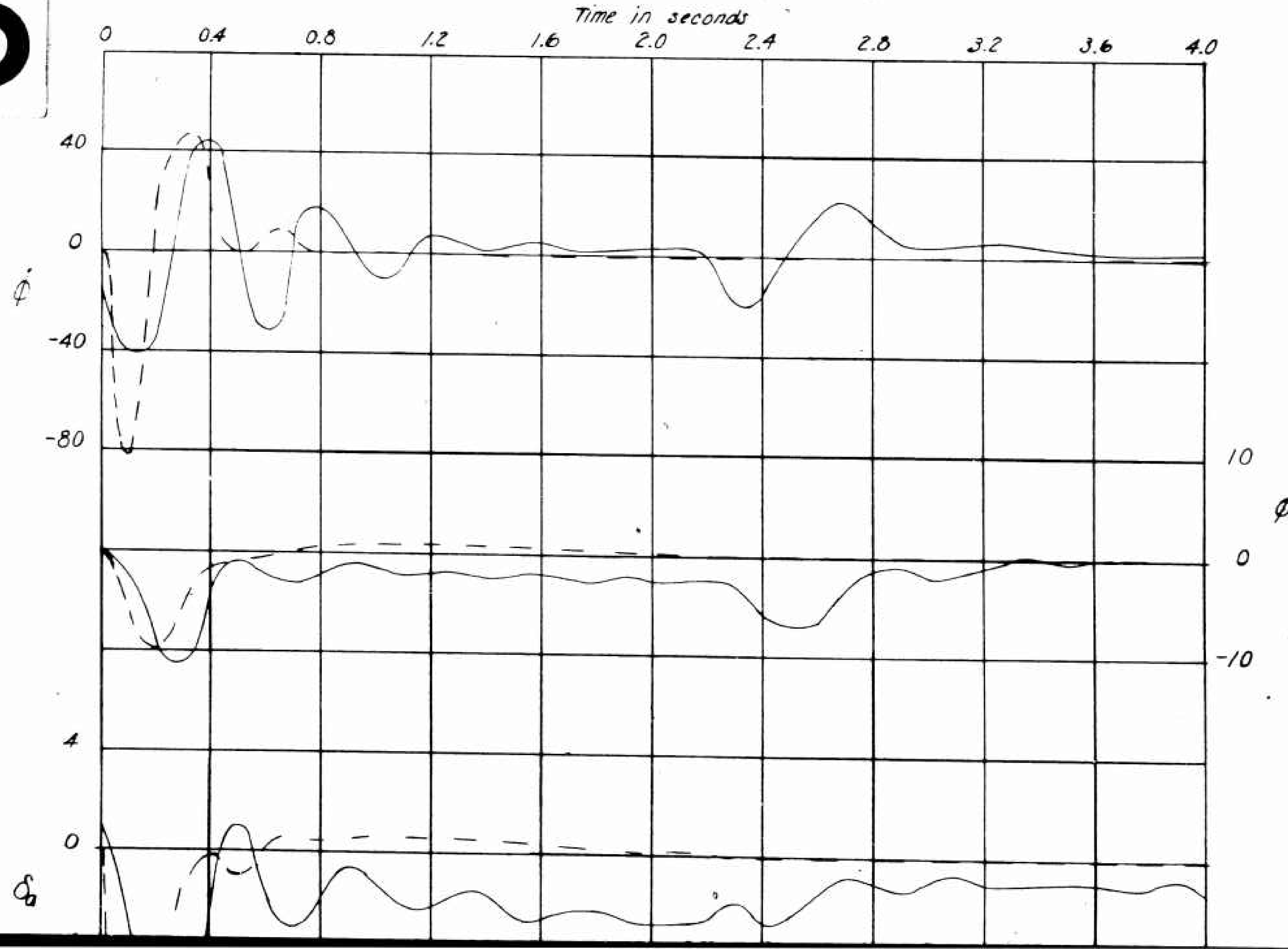


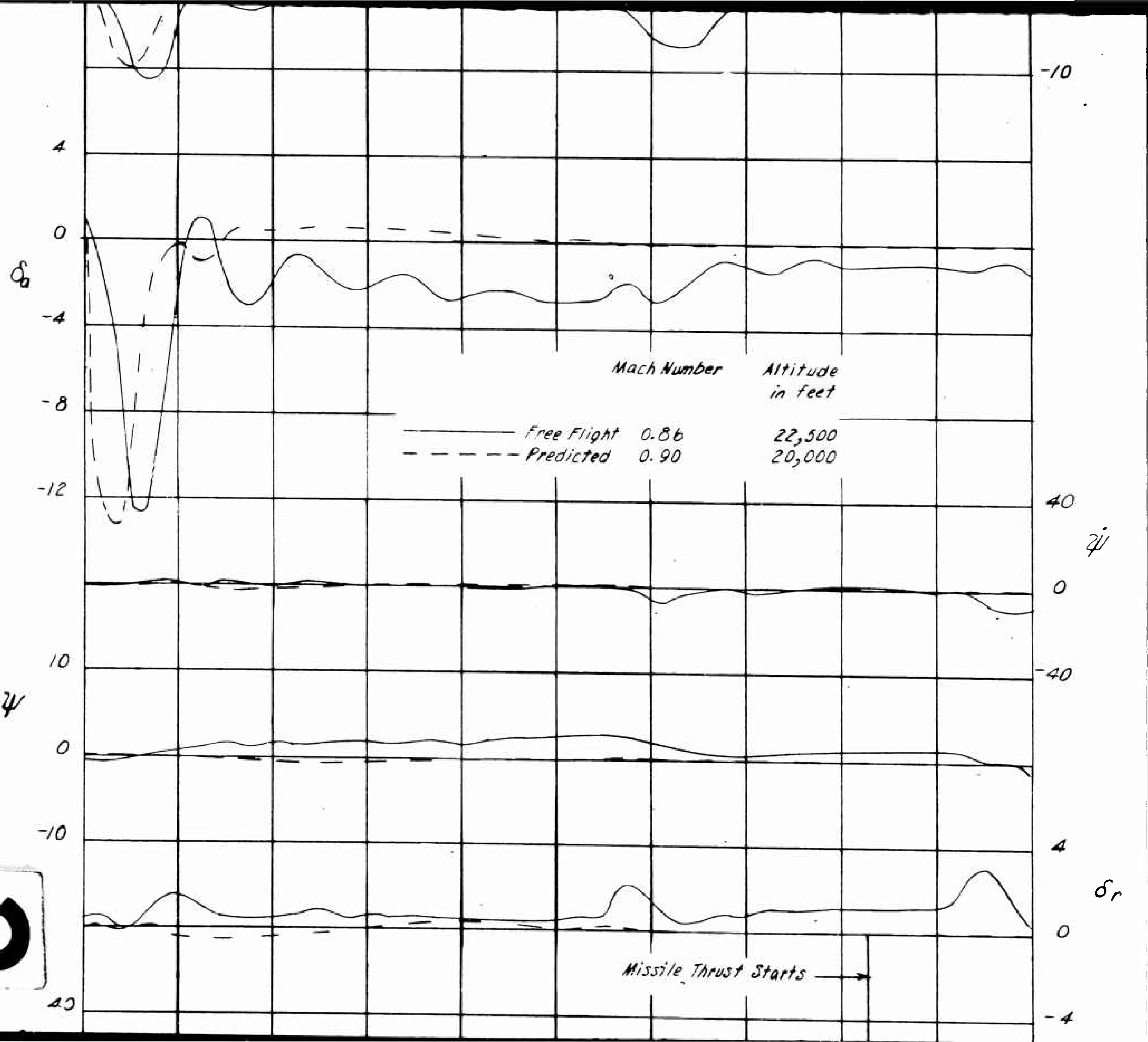
Time in seconds
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0

1


600
0
2
4
6
8
10
Time in seconds

2


Time in seconds
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
40
0
-40
-80
$\dot{\phi}$
10
ϕ
0
-10
4
0
δ_a



4
0
δ_a
-4
-8
-12
10
ψ
0
-10
40
-10
40
$\dot{\psi}$
0
-40
4
δ_r
0
-4
Mach Number
Altitude in feet
Free Flight 0.86 22,500
Predicted 0.90 20,000
Missile Thrust Starts

3

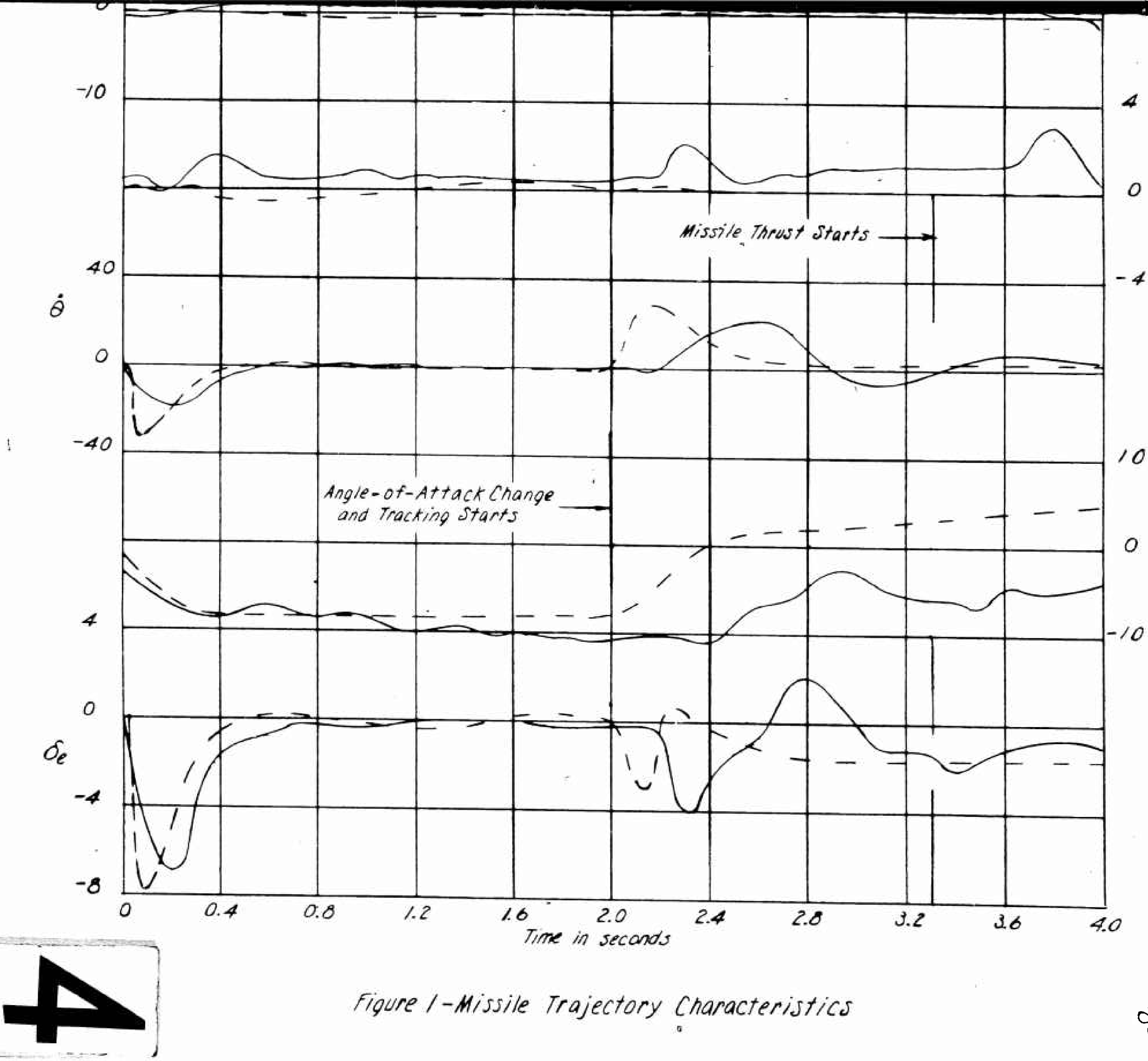


Figure 1-Missile Trajectory Characteristics

FIGURE 1

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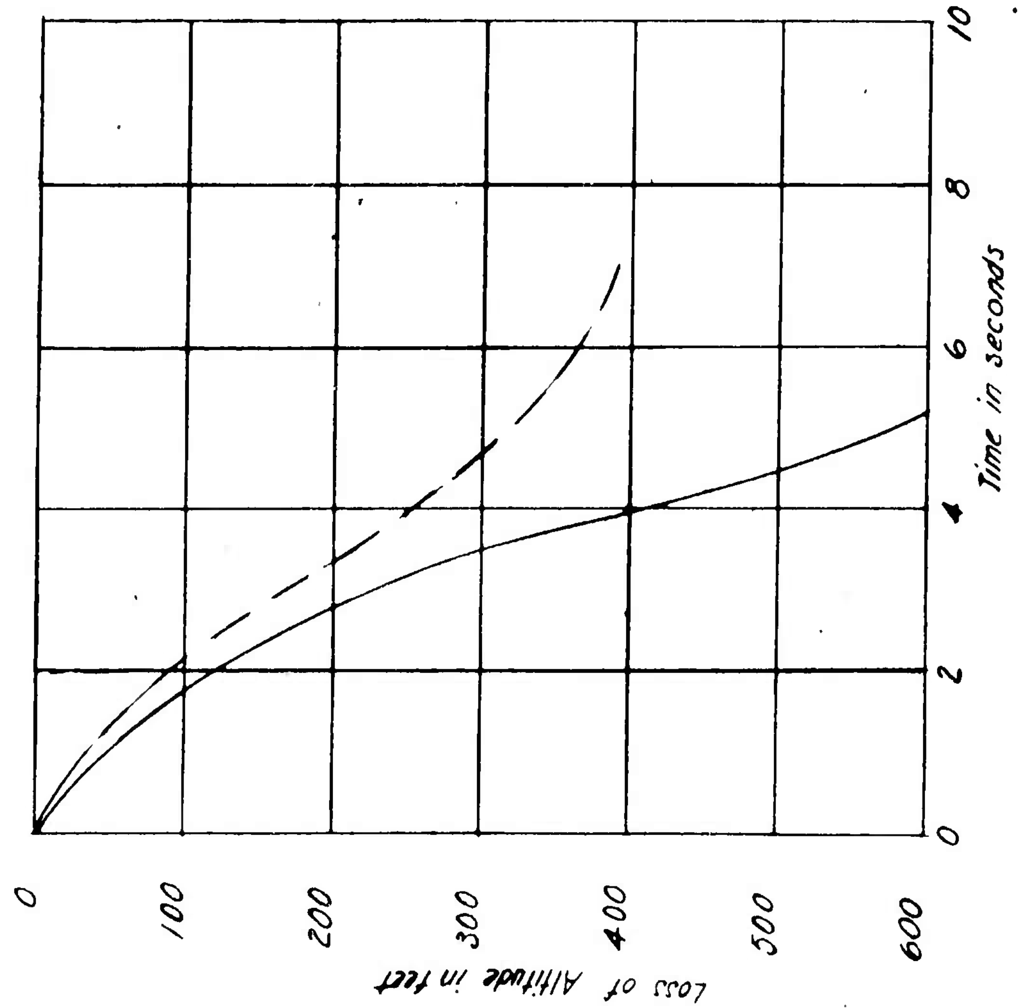
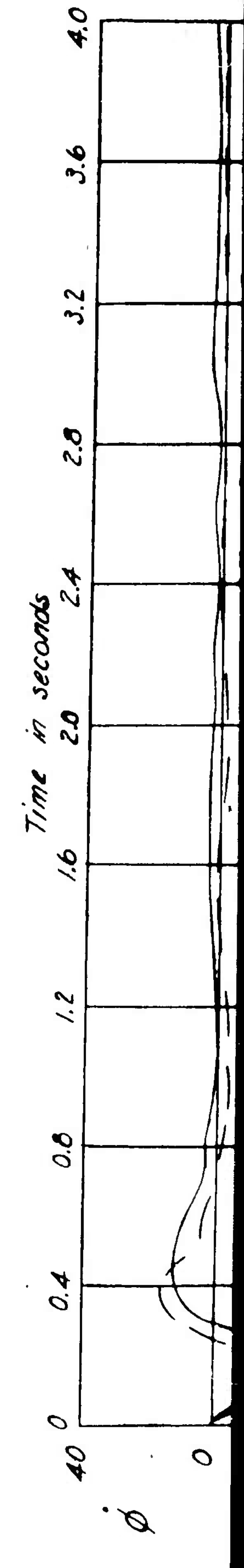
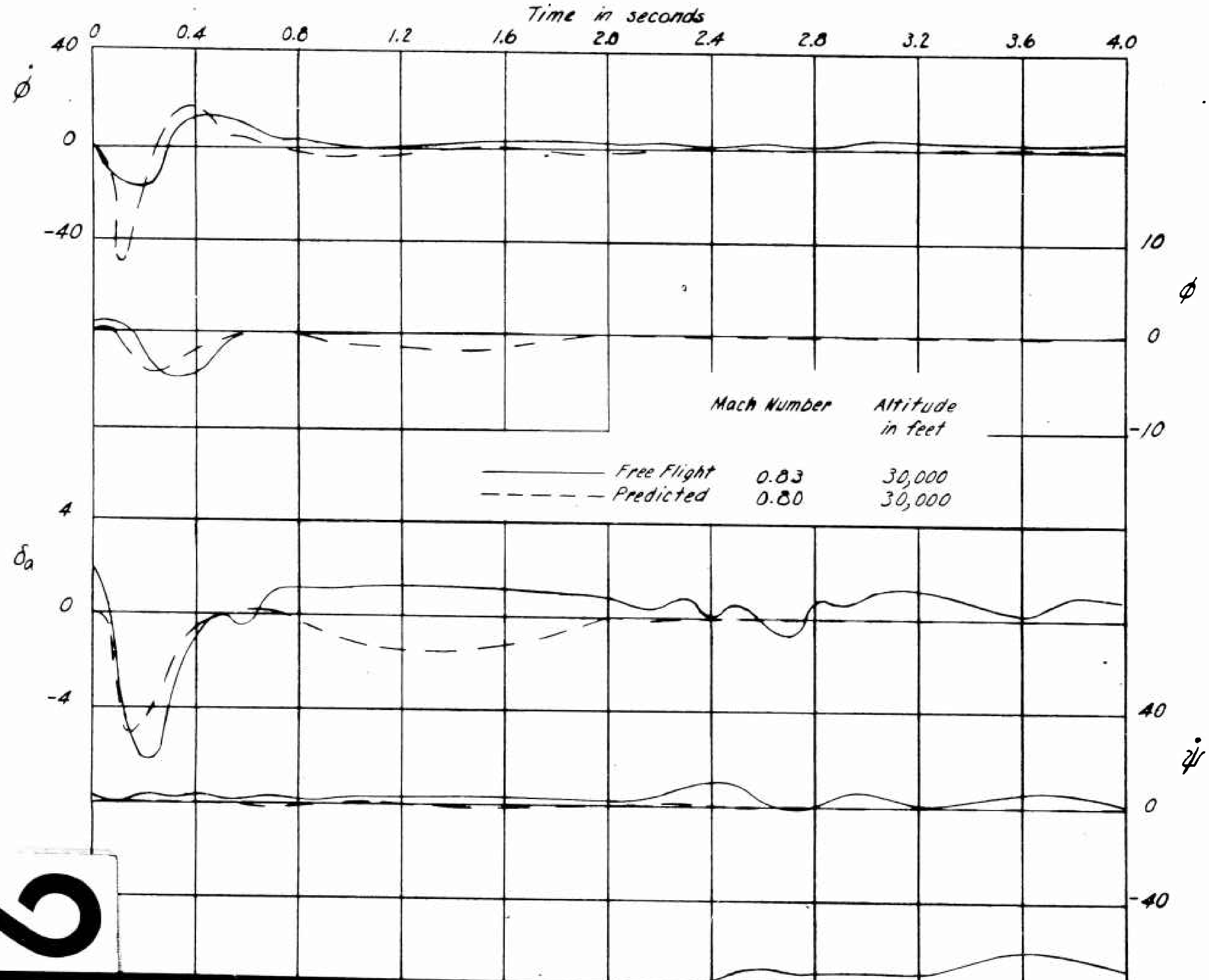


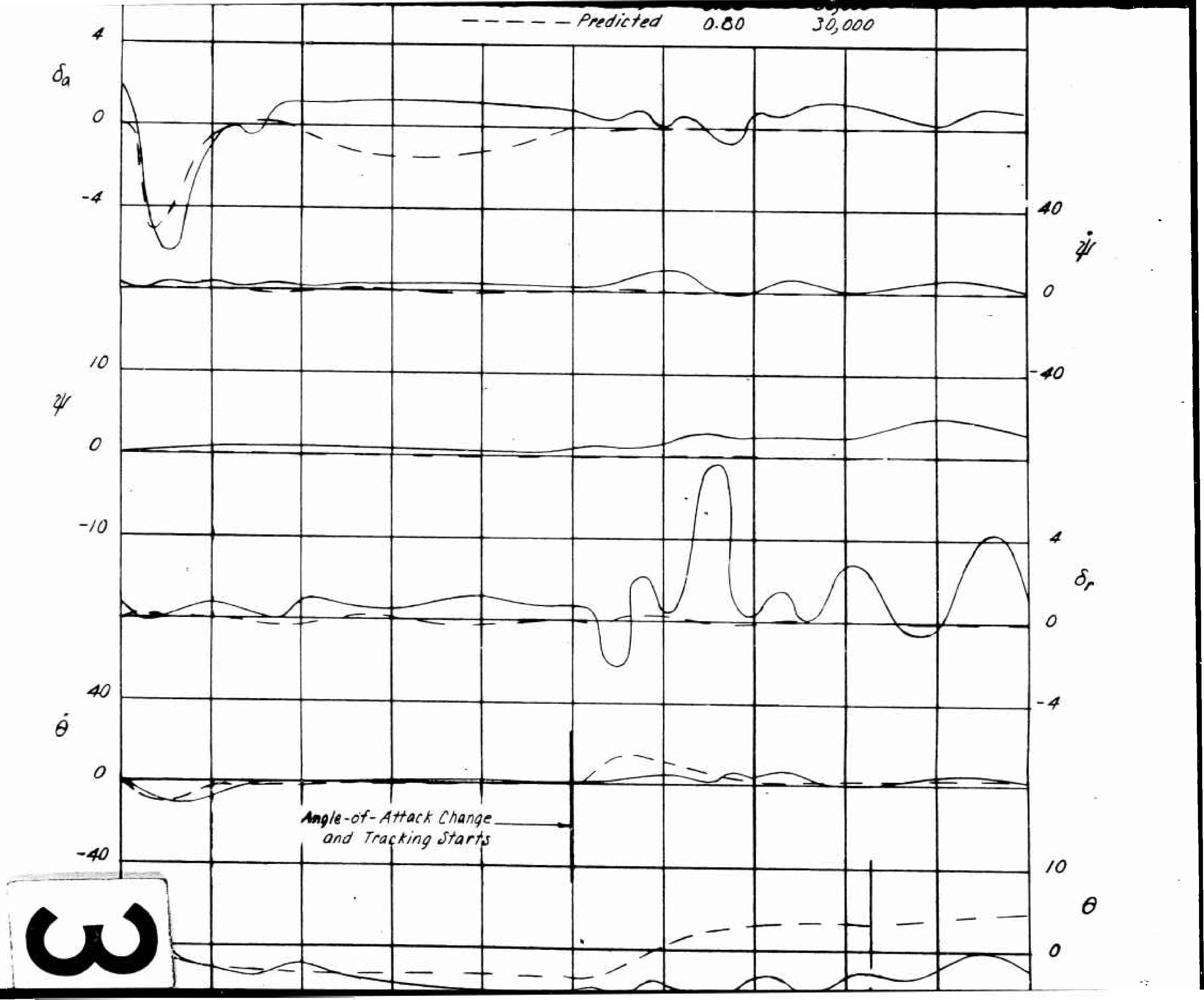
0
2
4
6
8
10
Time in seconds
0
100
200
300
400
500
600
Loss of Altitude in feet

1



0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
Time in seconds
40
0


Time in seconds
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
$\dot{\phi}$
40
0
-40
ϕ
10
0
-10
Mach Number
Altitude in feet
Free Flight 0.83 30,000
Predicted 0.80 30,000
δ_a
4
0
-4
$\dot{\psi}$
40
0
-40



- - - - - Predicted 0.80 30,000
δ_a
4
0
-4
ψ
10
0
-10
$\dot{\theta}$
40
0
-40
$\dot{\psi}$
40
0
-40
δ_r
4
0
-4
θ
10
0
Angle-of-Attack Change and Tracking Starts
3

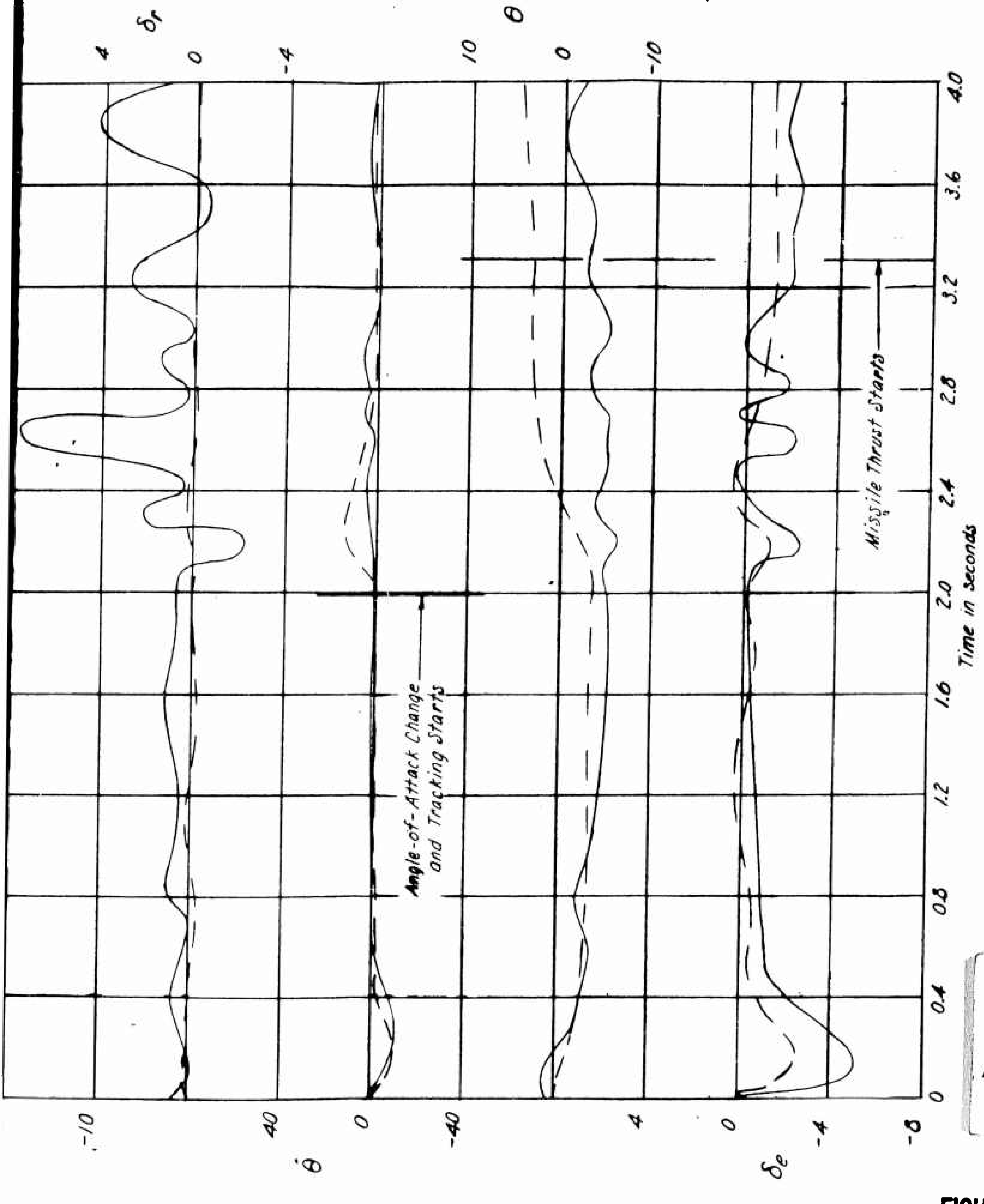


Figure 2-Missile Trajectory Characteristics

4

FIGURE 2

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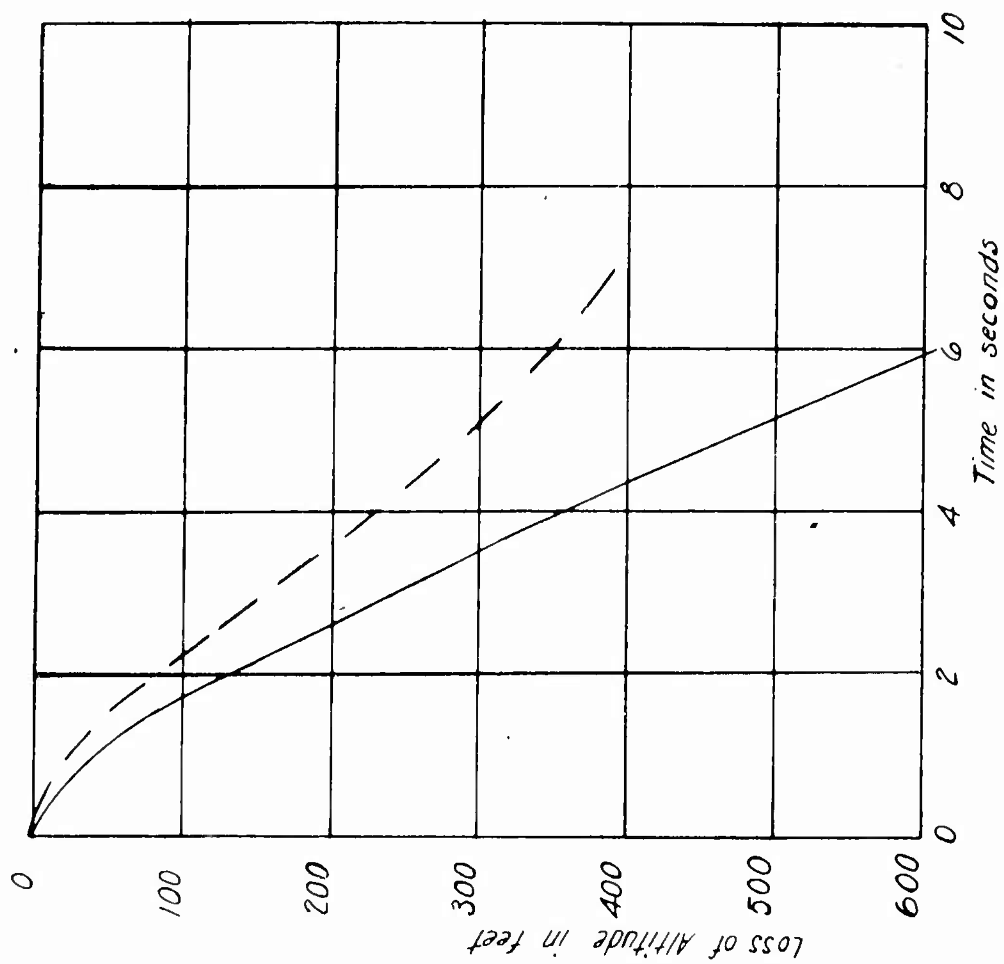
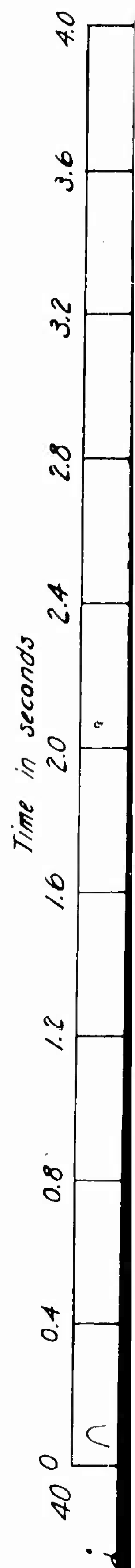
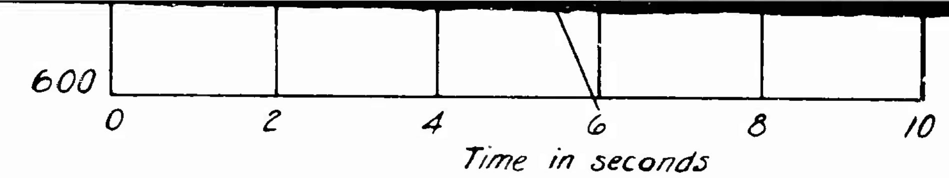
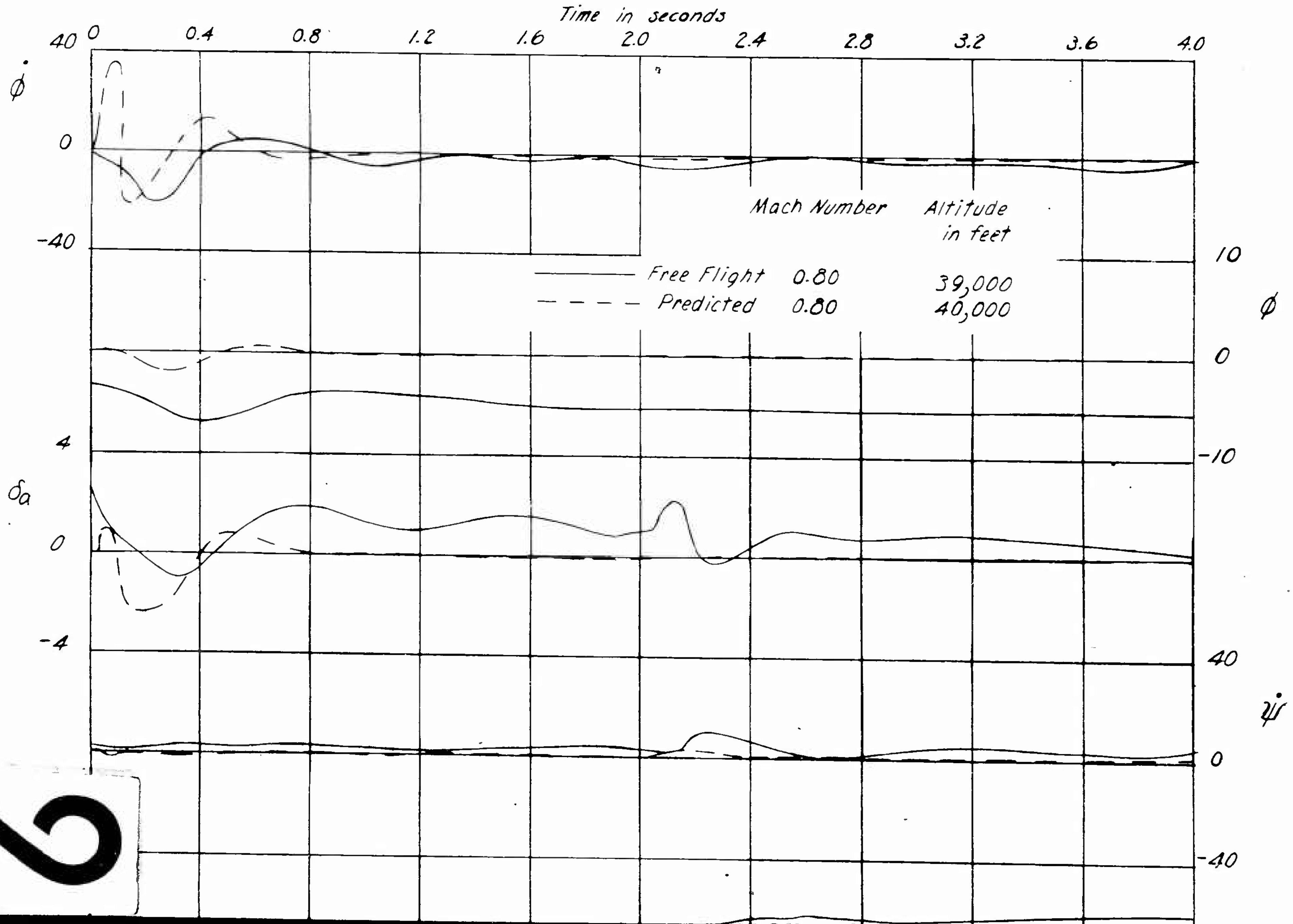

0
2
4
6
8
10
Time in seconds
0
100
200
300
400
500
600
Loss of Altitude in feet

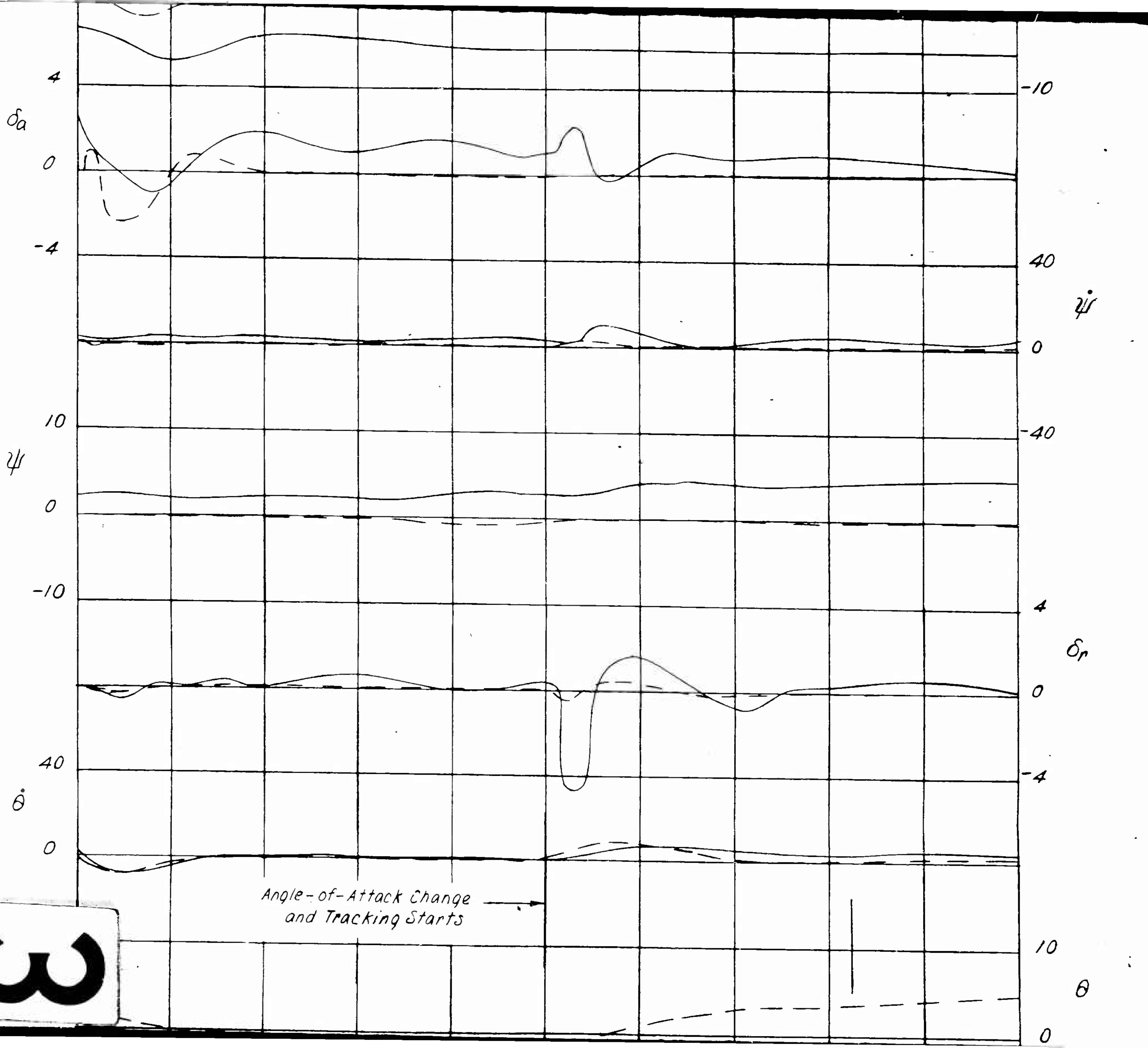

0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
Time in seconds
40

1


600
0
2
4
6
8
10
Time in seconds


Time in seconds
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
40
$\dot{\phi}$
0
-40
4
δ_a
0
-4
10
ϕ
0
-10
40
$\dot{\psi}$
0
-40
Mach Number
Altitude in feet
Free Flight 0.80 39,000
Predicted 0.80 40,000

2



4
δ_a
0
-4
10
ψ
0
-10
40
$\dot{\theta}$
0
-10
40
$\dot{\psi}$
0
-40
4
δ_r
0
-4
10
θ
0
Angle-of-Attack Change
and Tracking Starts

3

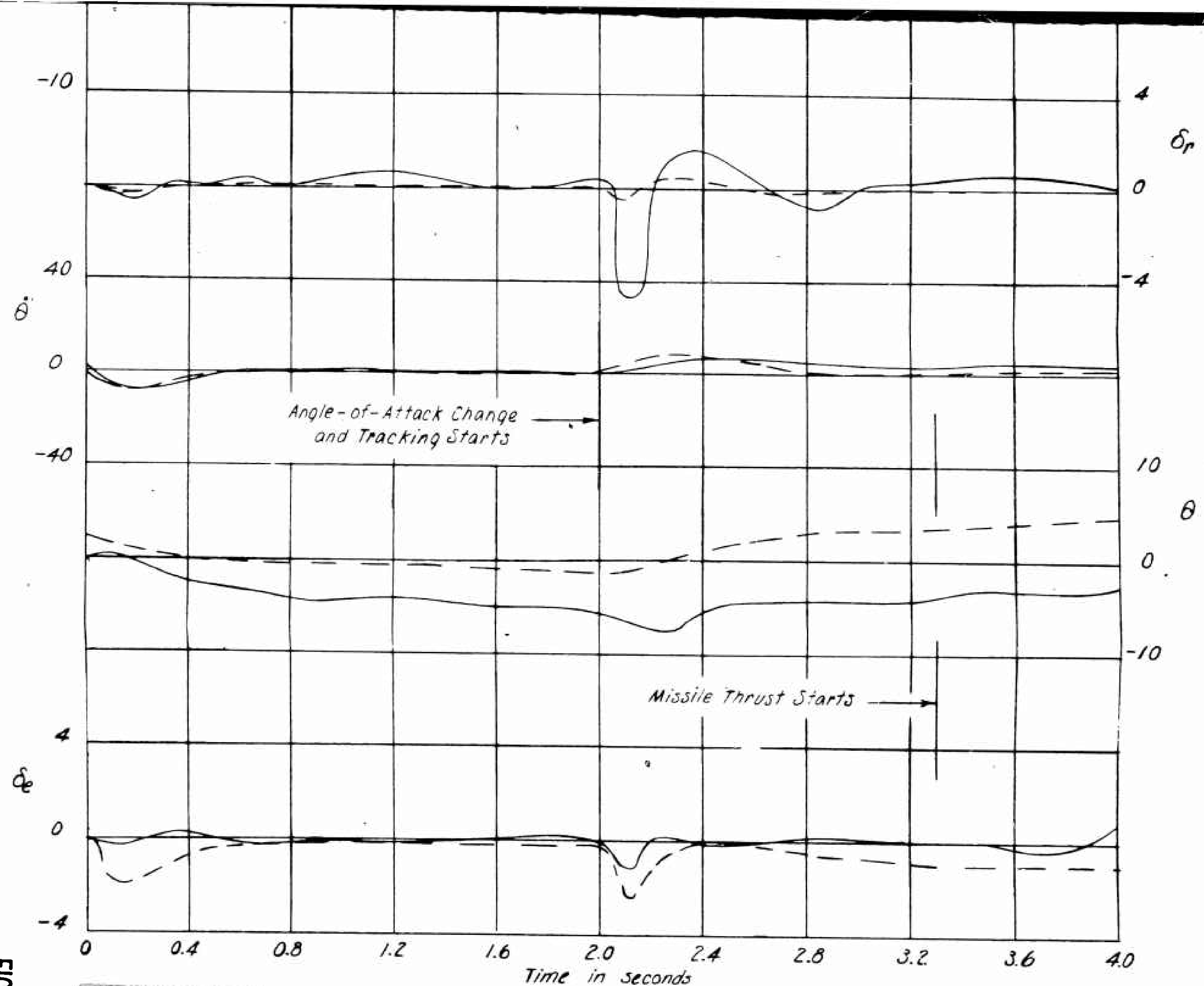


Figure 3 - Missile Trajectory Characteristics

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FIGURE 3

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On cover: [BuWeps] Problem Assignment 3-32-04.
Some Naval Missile Center full-scale aircraft missile trajectory characteristics following launch from an A3D-2 airplane are compared with those predicted from TMB Transonic Wind-Tunnel investigations. Mutual interference was accounted for during 1st second. Missile has low delta wing and cruciform tail. Predicted characteristics believed to be in good agreement. Analysis-type report.

1.EXTERNAL STORES--TRAJECTORIES--POINT-PREDICTION METHOD
2.GUIDED MISSILES--TRAJECTORIES
3.AIRPLANES (DOUGLAS A3D-2)
4.INTERFERENCE
5.WINGS, DELTA
6.TAILS, CRUCIFORM
7.TAILS, ALL-MOVABLE

I.Bamber, Millard John
II.DTMB Aero Test C-95
III.BuWeps Prob Assigt 3-32-04

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AIRCRAFT STORE TRAJECTORIES PREDICTED FROM WIND-TUNNEL INVESTIGATIONS COMPARED WITH FULL-SCALE FLIGHT RESULTS, by Millard J. Bamber. Wash., Jul 1961. 10 l. incl. illus. 3 refs. (Aerodynamics Lab. Aero Rpt 1011. Aero Problem 640-095)
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7.TAILS, ALL-MOVABLE

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